The effects of ingested plastic on growth and survival of albatross chicks

Paul R. Sievert[1] and Louis Sileo

National Wildlife Health Research Center, U.S. Fish and Wildlife Service, 6006 Schroeder Road, Madison, WI 53711

Abstract

We studied the effects of ingested plastic on the growth and survival of chicks of Laysan Albatrosses *Diomedea immutabilis* and Black-footed Albatrosses *D. nigripes* on Midway Atoll during the nesting seasons of 1986 and 1987. Weights and proventricular contents of the chicks were determined periodically through the nesting cycle. Large (>22 cm^3) volumes of plastic were present in the proventriculi of 27% of the Laysan and 16% of the Black-footed albatross chicks examined by endoscopy. Prior to fledging, albatross chicks regurgitated pellets composed of plastic and other indigestible material from their proventriculi. Laysan Albatross chicks with large volumes of proventricular plastic had asymptotic fledging weights significantly lower (122 g) than did chicks with low amounts of plastic. The effect of depressed fledging weights on postfledging survival was not determined. Plastic had no detectable effect on the growth of Black-footed Albatross chicks. All chicks that died were examined by necropsy. Mechanical lesions from ingested plastic were the cause of death of one of 45 Laysan Albatross chicks examined in 1986, but were not the cause of death of 93 individuals examined in 1987. Dehydration was the most common cause of death. In general, ingested plastic was not a significant direct cause of death in nestlings, but there was some evidence that it may have affected survival in 1986, when the volume of plastic ingested was highest.

Résumé

Les auteurs ont étudié les effets de l'ingestion de plastique sur la croissance et la survie des petits des espèces Albatros de Laysan *Diomedea immutabilis* et Albatros à pattes noires *D. nigripes*, dans l'atoll Midway, pendant les saisons de nidification de 1986 et 1987. Ils ont périodiquement pesé les petits et déterminé le contenu de leur estomac glandulaire, au cours du cycle de nidification. Au moyen des techniques d'endoscopie, ils ont relevé de forts volumes de plastique (> 22 cm^3) dans l'estomac de 27 % des petits d'Albatros de Laysan et de 16 % des petits d'Albatros à pattes noires. Avant le premier envol, les petits ont régurgité des pelotes, composées de plastique et d'autres substances indigestibles. Les petits d'Albatros de Laysan, qui présentaient un fort volume de plastique dans leur estomac glandulaire, affichaient un poids très inférieur (122 g) à celui des autres petits. Les auteurs n'ont pas déterminé l'effet de la perte de poids sur la survie après le premier envol. Ils n'ont pas constaté d'effet sur la croissance des petits d'Albatros à pattes noires. Ils ont examiné tous les sujets morts, au moyen des techniques de nécropsie. Les lésions morphologiques imputables à l'ingestion de plastique étaient la cause d'un décès parmi les 45 petits d'Albatros de Laysan examinés en 1986 et n'étaient la cause d'aucun décès parmi les 93 sujets examinés l'année suivante. La déshydratation était la cause de mortalité la plus fréquente. En règle générale, l'ingestion de plastique n'est pas une cause directe importante de mortalité dans les couvées d'albatros, malgré qu'elle ait pu affecter la survie des petits en 1986, année d'observation des volumes les plus élevés de plastique.

1. Introduction

Dumping of plastic in the oceans has increased dramatically in the last 30 years and has raised concerns about the impact of plastic on the health of marine organisms. Currently, 80 species, or approximately 25% of the world's seabird species, are known to ingest plastic (Sileo et al. 1991). Ingestion of plastics has been noted from all oceans and therefore has potential broad impacts on seabird populations and marine communities in general. The effects of ingested plastic on the health of marine birds are therefore of great interest.

The assessment of the impact of ingested plastic on seabirds has been very difficult, and most studies have had to rely on data correlating parameters affecting survival or reproduction to the amount of plastic ingested. Results from these studies are varied, with some showing statistically weak negative correlations between ingested plastic and bird mass or fat indices (Day 1980; Connors and Smith 1982; Furness 1985a, 1985b), whereas others find no effect of ingested plastic on body condition (Ryan 1987). The usefulness of correlation analyses is limited, as Ryan (1987) has stated, because of the difficulty of separating cause from effect. Controlled experiments are rare, and have not yet provided conclusive evidence of harm from ingestion of plastics. Ryan (1988b) found that chickens that had been fed plastic pellets ate less and grew more slowly than did control birds. This was in contrast to previous results for White-chinned Petrels *Procellaria aequinoctialis* that showed no change in assimilation efficiency or rate of mass loss between birds fed large quantities of plastic particles and controls (Ryan and Jackson 1987). Because of the paucity of controlled studies and their variable findings, we began a study in 1986 to assess the impact of ingested plastics on the growth and survival of Laysan Albatross *D. immutabilis* and Black-footed Albatross *D. nigripes* chicks on Midway Atoll.

[1] Current address: Department of Biology, University of Pennsylvania, Philadelphia, PA 19104.

Laysan and Black-footed albatross chicks were selected for study because they are known to ingest the widest variety of plastic items (Kenyon and Kridler 1969), and contain larger volumes of plastic than have been reported for any other seabird (Sileo and Fefer 1987). In addition, the docile nature of these birds and their high nesting density make them ideal for controlled field studies requiring large sample sizes. The goal of this research was to study the impact of ingested plastic on albatross chicks by using two types of field experiments. In the first experiment we fed some chicks plastic, and in the second experiment we compared chicks that were fed different volumes of plastic by their parents. The impact was evaluated in terms of chick growth and survival to fledging.

2. Methods

The study was conducted on Sand Island, Midway Atoll (28°11′N, 177°22′W), located 2100 km northwest of Honolulu, Hawaii. Approximately 200 000 pairs of Laysan Albatrosses and 7500 pairs of Black-footed Albatrosses nest on the two islands of the atoll (Fefer et al. 1984). A U.S. Naval Air Facility is located on Sand Island, and albatrosses nest around the facility's buildings and in less disturbed areas on the island. The study sites were located in open fields of grass and Compositae forbs found within ironwood *Casuarina litorea* forest. Entry to these areas was restricted by the U.S. Navy, and so the only human disturbance was due to our movements within the colony.

Laysan Albatrosses begin arriving at the colony in the first week of November and lay eggs from 20 November to 16 December; 90% of the eggs hatch from 25 January to 8 February, and the chicks fledge throughout July. Black-footed Albatrosses begin arriving at the colony in the third week of October and lay eggs from 13 to 30 November; 90% of the eggs hatch from 18 to 31 January, and the chicks fledge throughout June (Rice and Kenyon 1962). The study occurred during only the latter portion of the chick-rearing period in 1986 (9 May–1 August) and spanned the entire chick-rearing period during 1987 (24 January–5 August).

In 1986, we conducted field experiments to determine whether plastic ingestion had a significant effect on the survival of Laysan Albatross chicks. Growth rates were not compared in this year, because the chicks already had attained their asymptotic weights when we arrived. Our approach was to monitor the fates of the following four groups of chicks with approximately 50 individuals per group: (1) naturally fed low amounts of plastic; (2) naturally fed high amounts of plastic; (3) artificially fed 100 cm^3 of plastic pellets; (4) artificially fed 200 cm^3 of plastic pellets. It should be noted that chicks naturally fed low amounts of plastic had to serve as our control group, because all Laysan Albatross chicks necropsied in this study and in a concurrent study of plastic prevalence in Hawaiian seabirds (Sileo et al. 1991) contained plastic. We quantified the amount of plastic in the proventriculus of chicks by viewing the contents with a fibre optics endoscope (Welch Allyn). The endoscope consisted of a hollow stainless steel barrel with an outside diameter of 11.5 mm and length of 255 mm and was attached to a 3.8-V halogen light handle that provided a mobile light source. A custom-designed extension to the original barrel lengthened the barrel to 410 mm and allowed the scope to be inserted into the esophagus and to the posterior portion of the proventriculus. The amount of plastic in the proventriculus of a chick could be measured by one person who restrained the bird between his or her legs and held the bird's bill open with one hand while inserting the endoscope into the esophagus with the other. Through the endoscope, floating plastic and other particles could be seen on the surface of the stomach oil. After viewing the oil surface, the endoscope was then inserted as far posteriorly in the proventriculus as possible. A chick was considered to have a low volume of plastic if the posterior wall of the proventriculus could be reached "easily." The chick was classified as having a high volume of plastic if the posterior wall could only be reached "with difficulty" or could not be reached at all. The chick was handled for 15–30 s in order to estimate its volume of plastic. By using the endoscope on 10 chicks that were found dead during the course of the study and then dissecting their proventriculi, we found that our low ranking corresponded to plastic volumes of ≤22 cm^3 and our high ranking to volumes >22 cm^3. The exact volume of plastic in a bird could not be determined with this method, because it was not possible to tell what fraction of the indigestible material below the stomach oil surface was plastic, pumice, or prey parts.

Two hundred chicks were examined from 9 May to 2 June, and 46 were classified as containing high volumes of plastic. The remaining 154 birds were divided into three groups, and 54 were not fed any plastic, 50 were fed 100 cm^3 of plastic pellets, and 50 were fed 200 cm^3 of plastic pellets. The plastic pellets were white polyethylene spheres 3–5 mm in diameter. Plastic was fed to the chicks by entubation and required handling the bird for 1–2 min. All chicks were marked with numbered plastic leg bands and checked at least once daily until fledging. All chicks that died during the study were necropsied, and selected tissues were saved for histological, bacteriological, and toxicological examination. The volume of plastic, rock, and food items removed from the proventriculus was measured by water displacement (Sileo et al. 1991).

In 1987, we began field work on 24 January and marked the nests of 400 Laysan and 250 Black-footed albatrosses. When the chicks were approximately six weeks of age they were marked with numbered plastic leg bands. Study areas were inspected 1–2 times a day for dead study chicks, and dead birds were necropsied and tissues saved as described above. Wing chord and mass of the chicks were measured weekly for the first 12 weeks and every two weeks thereafter until fledging. All chicks were examined using the endoscopic technique described above during three time periods: 23 Feb.–6 Mar., 6 May–13 May, and 17 Jun.–6 Jul. No chicks were fed plastic artificially. If a chick was found to have a high volume of plastic during any one of these three examinations, it was classified as ingesting a high volume of plastic; otherwise, it was considered to ingest a low volume of plastic.

Four other types of information were obtained to assist in interpreting the experimental results: (1) frequency that chicks were fed; (2) seasonality of bolus regurgitation; (3) number of carcasses of Laysan Albatross chicks collected daily around the Naval Facility buildings; and (4) daily high temperatures. Frequency of feeding was determined by daily weighing of 20 Laysan and 20 Black-footed albatross chicks. We assumed that pronounced weight gain in a 24-h period meant that a chick had been fed in the previous 24 h. Seasonality of bolus regurgitation was described by daily counting and removal of castings from the study site. The number of Laysan Albatross carcasses collected daily and daily maximum temperatures were supplied by Base Services, Inc. (civilian contractor for the U.S. Naval Facility).

We compared survival rates with chi-square tests. Growth rate, as measured by wing chord, was analyzed by fitting the measurements to a linear equation. Growth rates, as measured by changes in body mass, were fitted with the Gompertz growth equation:

$$W = Ae^{-e^{k(d-I)}}$$

where: W = weight
A = asymptotic weight
k = constant proportional to overall growth rate
d = day, and
I = number of days to reach the inflection point of the growth curve.

Slopes of the lines fitted to wing chord growth, and parameters from fitted Gompertz growth curves, were analyzed using a multivariate analysis of variance.

3. Results

In 1987, the percentage of Laysan and Black-footed albatrosses containing high volumes of proventricular plastic changed over the chick-rearing period (Table 1). At about four weeks of age, only 0.8% of the Laysan chicks had high amounts of plastic; this frequency increased to 26.6% by the second week of May, then decreased to 9.7% in the latter half of June. Black-footed Albatross chicks showed a continual increase in plastic accumulation from late February (0%) to late June (15.5%). The number of boluses of plastic and other indigestible items regurgitated by albatross chicks showed a bimodal distribution, with peaks in regurgitation occurring the last two weeks of May and June (Fig. 1). During 1986, we noted that some of the boluses contained plastic pellets that had been artificially fed to experimental chicks.

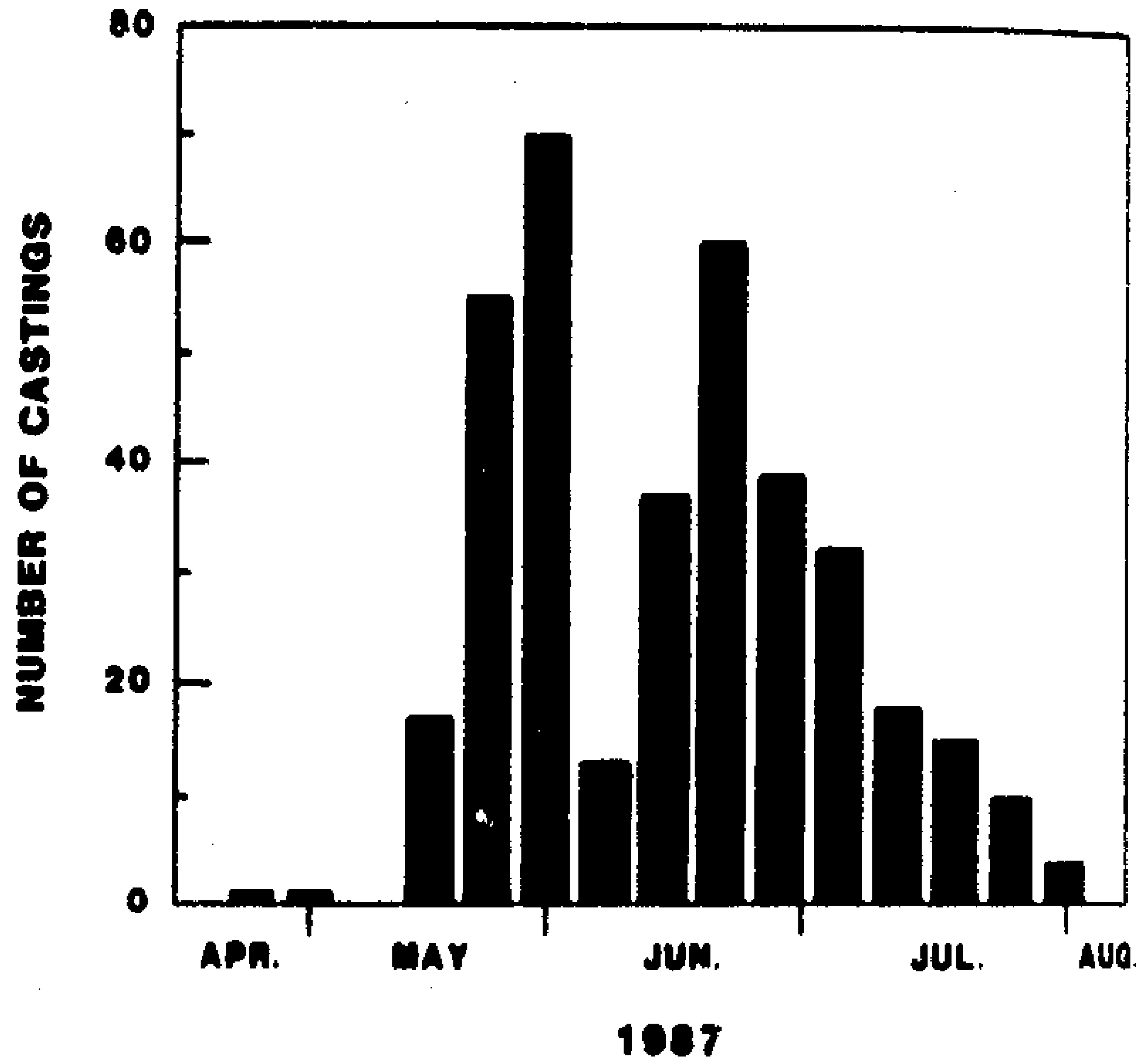
There was a dramatic seasonal trend in the number of Laysan Albatross chicks dying near U.S. Naval Facility buildings in both years of the study (Fig. 2). In 1986, 18 300 chicks died, and in 1987, 17 300 died. During 1986, Laysan Albatross chicks that ingested high volumes of plastic had significantly lower survival rates than did those ingesting low volumes (Table 2). The percentages surviving of those chicks fed 100 cm^3 and 200 cm^3 of plastic pellets were 74.0% and 62.0%, respectively, which did not differ significantly from the value for chicks naturally fed low volumes of plastic, 75.9% ($\chi^2 = 0.051$, $P = 0.821$, d.f. = 1; and $\chi^2 = 2.364$, $P = 0.124$, d.f. = 1, respectively). In 1987, chicks of both albatross species showed no significant difference in the percentage surviving due to natural ingestion of high or low volumes of plastic (Table 2).

Ingested plastic was implicated directly in the death of only one of 174 chicks examined by necropsy (Table 3). Although the cause of death of many of the chicks was not determined, none of the carcasses had the debilitating proventricular ulcers or fistulas associated with the one fatal case of plastic ingestion. Dehydration was the most common cause of death. In general, the dehydrated carcasses were in excellent flesh, suggesting that food intake was adequate. Chigger infestation (trombidiosis), starvation, trauma, nocardiosis, lead toxicosis, omphalitis, and bacteremia were other causes of death. A diagnosis of dehydration was probably precluded for some of the carcasses, because the subtle lesions were obscured by rapid decomposition and artifact from frozen storage.

Table 1
Seasonal changes in the percentage (percent/sample size) of Laysan and Black-footed albatross chicks containing large volumes of plastic (>22 cm^3) in their proventriculi during 1987 on Midway Atoll. The volume of plastic was determined by inspection of the proventriculus with a fibre optics endoscope.

Species	Sampling period		
	23 Feb.–6 Mar.	6 May–13 May	17 Jun.–6 Jul.
Laysan Albatross	0.8/370	26.6/350	9.7/267
Black-footed Albatross	0.0/28	3.9/180	15.5/142

Figure 1
Number of new castings collected per week in nesting colonies of Laysan and Black-footed albatross chicks on Sand Island, Midway Atoll, 1987



For both 1986 and 1987, the mean daily maximum temperature per week showed a slightly increasing trend from 1 February to mid-May, then rose sharply until the second week of July, and finally declined slightly by the end of July (Fig. 3). In 1986, the weekly mean for the second week of May was 22.1°C and for the second week of July was 29.5°C. In 1987, these values were 23.3°C and 30.8°C, respectively.

The number of feedings a chick received per week decreased over the course of the chick-rearing period. For Laysan Albatrosses, the mean number of feedings per week was 6.5 for the first week after hatching and only 1.1 just before fledging. The values for Black-footed Albatross chicks were 6.3 and 1.2 feedings per week, respectively.

In 1987, the asymptotic weight of Laysan Albatrosses with high volumes of proventricular plastic was 122 g lower ($F = 0.002$, d.f. = 1) than that for chicks with low volumes of plastic (Table 4). The growth curve asymptote is statistically associated with the inflection point and growth rate, and these latter two parameters were significantly different for birds with high amounts of proventricular plastic. Plastic had no effect on the body weight gains of Black-footed Albatrosses or on the wing chord growth of either species (Table 4).

4. Discussion

4.1. Temporal variation in proventricular plastic volume

When analyzing the effects of plastic ingestion on albatross chicks, it is important to consider the seasonality of

Figure 2
Number of dead Laysan Albatross chicks picked up weekly at the Midway Naval Air Facility during 1986 and 1987

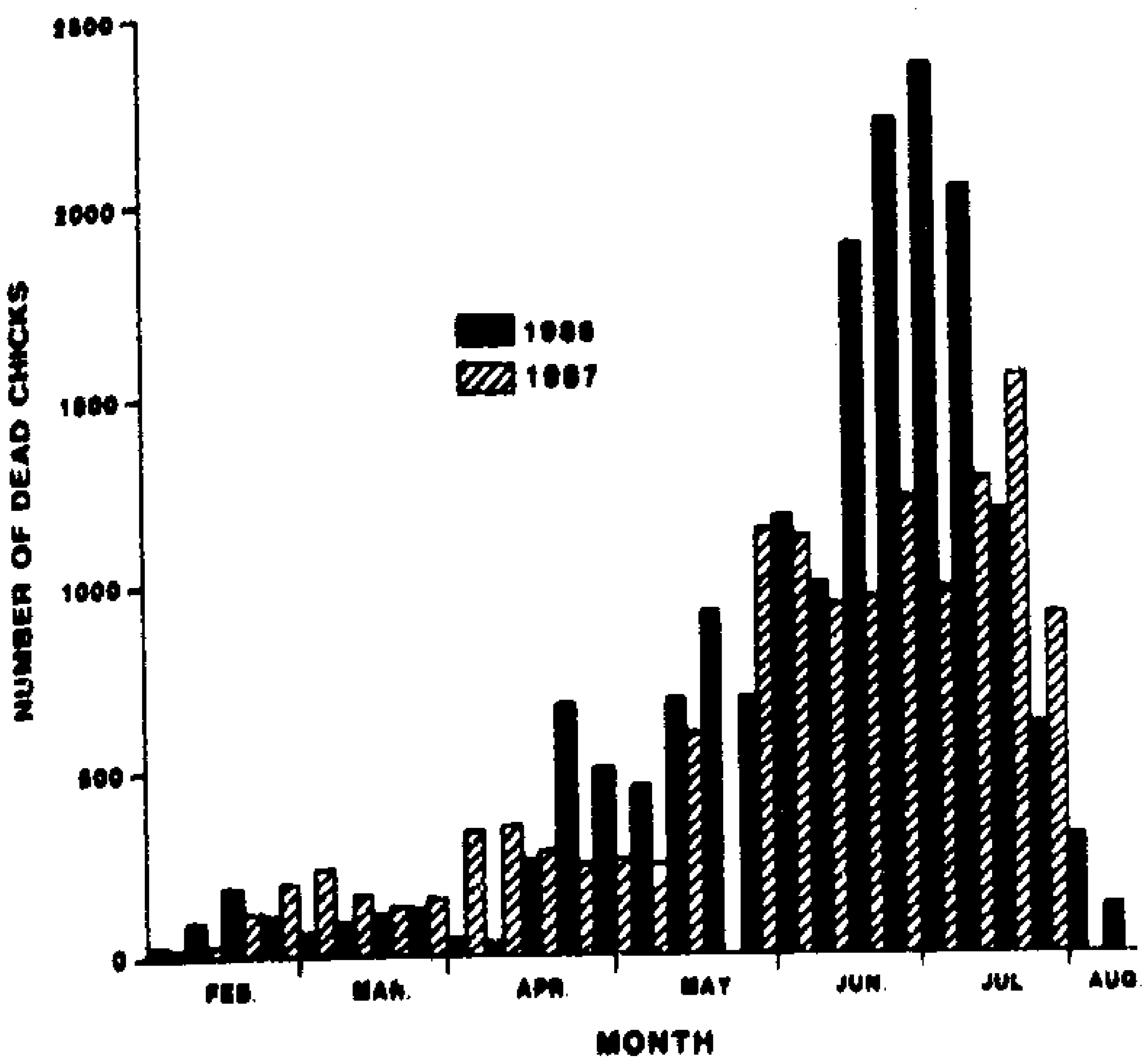


Figure 3
Mean daily high temperatures for each week on Sand Island, Midway Atoll, from 1 February through 26 July 1986 and 1987

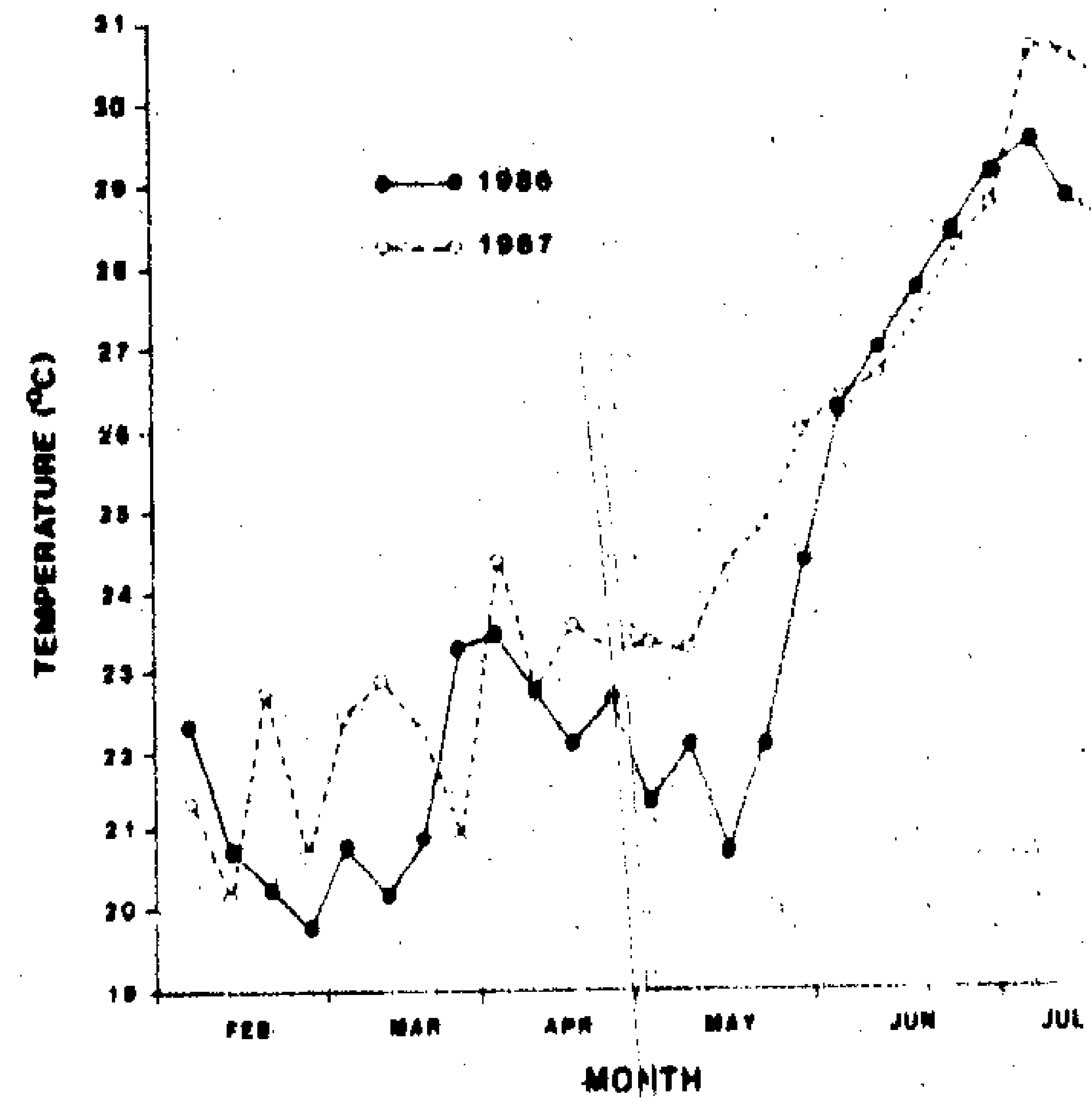


Table 2
Survival (percent surviving/sample size) of Laysan and Black-footed albatross chicks containing high (>22 cm³) or low (<22 cm³) amounts of proventricular plastic, 9 May–1 August 1986 and 6 May–5 August 1987

Species	Year	Plastic volume Low	High	Chi-square	P value
Laysan Albatross	1986	75.9/54	54.3/46	5.154	0.023
Laysan Albatross	1987	78.3/240	84.8/112	2.040	0.153
Black-footed Albatross	1987	87.3/134	82.6/23	0.375	0.540

Table 3
Number of Laysan and Black-footed albatross chicks dying from different causes on Midway Atoll during 9 May–11 July 1986 and 1 February–31 July 1987

Cause of death	1986 Laysan Albatross	1987 Laysan Albatross	1987 Black-footed Albatross
Unknown	33	60	26
Plastic impaction	1	0	0
Dehydration	0	23	4
Starvation	3	0	0
Trombidiosis	5	2	2
Nocardiosis	0	0	1
Lead toxicosis	0	1	0
Omphalitis	0	1	0
Bacteremia/peritonitis	0	1	0
Trauma	0	1	1
Multiple causes	3	4	2
Total	45	93	36

plastic occurrence in the proventriculus. Over the course of the chick-rearing period, there was a distinct change in the volume of plastic present in the proventriculi of Laysan Albatross chicks. In 1987, high volumes of plastic were rarely found in chicks during the first six weeks following hatching. This may be because there was a necessary lag time required for the build-up of a large volume of plastic in the chick's proventriculus. Alternatively, meals during this time may have been smaller and therefore reduced the probability of plastic being passed to the chick, assuming that the volume of plastic in a meal is proportional to meal size. By the second week of

Table 4
Correlations of high (>22 cm³) and low (<22 cm³) volumes of proventricular plastic with growth parameters of Laysan and Black-footed albatross chicks on Midway Atoll in 1987

Parameters	Low volume	High volume	Prob. [illegible]
Laysan Albatross			
Sample size	[illegible]	100	
Wing chord slope[a]	0.01796	[illegible]	[illegible]
Asymptotic weight[b]	2836	2714	[illegible]
Days to reach inflection[b]	19.0	[illegible]	[illegible]
Growth rate constant[b]	0.0500	0.0558	[illegible]
Black-footed Albatross			
Sample size	102	[illegible]	
Wing chord slope[a]	0.01830	0.01828	[illegible]
Asymptotic weight[b]	3558	3412	[illegible]
Days to reach inflection[b]	23.0	22.6	[illegible]
Growth rate constant[b]	0.0564	0.0543	[illegible]

[a] Wing chord growth was described using linear equations and the slopes of the fitted lines were then compared.
[b] Growth, as indicated by weight change, was modelled using the Gompertz equation (see text).

May, approximately one-fourth of the chicks had accumulated high volumes of plastic, and, at this point, plastic may have had its strongest effect. By late June, the percentage of Laysan Albatross chicks having high plastic volumes had declined, probably because of the peak in bolus regurgitation that occurred during late May and early June. Chicks could have emptied their proventriculi of indigestible material to make room for feedings from their parents or tried reducing their weight as they began to take short flights within the colony in preparation for fledging in mid-July.

The percentage of Black-footed Albatross chicks containing high volumes of plastic increased throughout the chick-rearing period. Apparently, this species did not regurgitate boluses according to the pattern described above and therefore did not reduce its plastic load during the last two months before fledging. This difference from the bolus pattern for Laysan Albatrosses was likely a result of our collecting boluses in colonies that consisted predominantly of Laysan Albatrosses. The increase in plastic accumulation up to the time of fledging means that Black-footed Albatross chicks either fledged with a large amount of plastic in their proventriculi or regurgitated boluses between their departure from the nest and their departure from the island.

Laysan Albatross chicks showed a dramatic decrease in mean volume of plastic ingested between 1986 (46 cm^3) and 1987 (5 cm^3) (Sileo et al. 1991). A significant correlation between survival and volume of plastic ingested was found only in the year of high plastic ingestion (1986) and emphasizes the need for long-term studies of plastic ingestion. Interannual variation has also been found in prions *Pachyptila* spp. (Harper and Fowler 1987; Ryan 1988a) and Red-tailed Tropicbirds *Phaethon rubricauda* (Sileo et al. 1991). Such differences may be caused by interannual changes in the amount of plastic dumped in the ocean, directions of currents, foraging area, or feeding habits.

4.2. Effect of plastic ingestion on the survival of albatross chicks

Necropsies in this study and by Sileo et al. (1990) showed that mechanical lesions from ingested plastic rarely are the direct cause of death in albatross chicks at Midway Atoll. The negative correlation between volume of ingested plastic and survival of Laysan Albatross chicks in 1986 suggests, however, that there is an indirect effect due to the ingestion of plastic. A high volume of proventricular plastic may reduce the amount of food, and hence water, that a chick can accept from an adult during feeding. Reduction of water intake may have a significant effect during hot periods when the chick is required to evaporate water at a high rate to be able to regulate its body temperature. From mid-May until fledging, the daily high temperatures increased while the frequency of feeding decreased. If the large volumes of plastic that accumulate in chicks during this time reduce water intake, the risk from dehydration should increase. Controlled experiments are needed to test this hypothesis, however. The negative correlation between volume of ingested plastic and survival may also be coincidental. Perhaps some other factor, such as poor hunting skills of certain adult albatrosses, causes both low survival and high plastic content in their chicks.

Decreased growth of albatross chicks may reduce their postfledging survival. In 1987, Laysan Albatross chicks that had ingested high volumes of plastic had lower asymptotic weights than those with low volumes, although their survival to fledging was unaffected. Ryan (1988b) found that chickens fed polyethylene pellets ate less and grew more slowly than did control birds. It may be that large volumes of plastic reduce the meal size that a chick can accept and, consequently, reduce the chick's growth and body mass at fledging. Reduced body mass may mean that energy stores, needed during the period of learning to forage, are critically limited. This question can only be addressed through long-term studies of marked birds, however.

Feeding polyethylene pellets did not affect the survival of Laysan Albatross chicks (this study) or the assimilation efficiency of White-chinned Petrels (Ryan and Jackson 1987). These results may be explained by the pellets' being an inadequate simulation of natural plastic ingestion or by plastic ingestion's being an innocuous phenomenon. Pellets may be an inadequate simulation because Laysan and Black-footed albatrosses ingest a wide variety of plastic types, with fragments of manufactured plastic being the most prevalent particles (Sileo et al. 1991). In addition, the fed pellets in this study were sometimes regurgitated following the artificial feeding, therefore reducing the effective sample size of the treatment. Replication of this experiment with irregular plastic particles, similar to commonly ingested pieces, would address this question. It is possible that the size and shape of individual plastic particles, rather than total plastic volume, are the characteristics having the greatest impact on the health of seabirds.

4.3. Conclusions

Our results indicate that ingested plastic is not a significant direct cause of death in albatross chicks. There is some evidence that plastic may indirectly affect survival during the nestling period and possibly after fledging. The volume of ingested plastic was negatively correlated with the survival of Laysan Albatross chicks in 1986 but not in 1987 and with fledging weight in 1987. Reduced fledging weight may reduce survival of chicks after their departure from the nesting colony. There was no correlation between volume of ingested plastic and survival or growth of Black-footed Albatross chicks. Feeding polyethylene pellets to Laysan Albatross chicks had no effect on survival, but these results may not be applicable to the natural situation in which chicks ingest irregular plastic fragments most commonly. The results demonstrate that the effect of plastic ingestion may vary between species and years. Experimental studies aimed at elucidating the mechanism by which plastic ingestion indirectly affects survival are necessary to ascertain whether these associations are results of a causal relationship.

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